Improving the Navy's Passive Underwater Acoustic Monitoring of Marine Mammal Populations

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LONG-TERM GOALS

The long-term goals of this research effort are to improve the Navy's passive underwater acoustic monitoring of marine mammal populations. A major focus in this project is on further enhancing the ability to estimate environmentally-calibrated calling density (calls per unit area per unit time) obtained from raw detections of calls in underwater acoustic recordings. The efforts in this program also will support the Ph.D. research of a graduate student in marine bioacoustics and ocean acoustics at the Scripps Institution of Oceanography.

OBJECTIVES

The specific objectives of this project are: 1) to further develop the methods for accurately estimating the densities of low-frequency-calling marine mammal species using passive acoustic monitoring, with application to obtaining density estimates of transiting humpback whale populations in the Southern California (SoCal) Bight, 2) to incorporate detection theory formalism into the acoustic density estimation procedure in order to minimize the variance of the density estimates, 3) to apply the numerical modeling methods for humpback whale vocalizations to understand distortions caused by propagation of humpback calls west of Kauai, Hawaii, and 4) to conduct spatial statistical analyses and correlation analyses of marine mammal and other bioacoustic sounds in the SoCal Bight with man-made underwater sounds, with physical properties of the environment, and with fields relevant to the biological productivity of the water column. The work in this project is heavily leveraged with other ongoing programs and efforts, as discussed in Related Projects below.

APPROACH

Passive underwater acoustic monitoring of marine mammal sounds is the Navy's primary method for characterizing the presence, distribution, and number of marine mammal species in several different environments. This project addresses several aspects of this monitoring effort in order to improve the scientifically relevant information that can be obtained from the recordings. The overall approach is to extend the research thrust of correcting for environmental properties in detections of marine mammal calls in passive underwater acoustic recordings, and to use these environmentally-corrected call

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detections to learn more about the animals themselves. Detected call counts are determined not only by the animals' calling characteristics, but also by the properties of the underwater environment in which the calls are recorded. First, propagation through the ocean environment can have a significant distorting effect on the recorded calls. This distortion can be strongly site dependent and dependent upon time of day and season. Second, the sounds from all other sources in the ocean ("noise") directly affect the ability to detect calls of interest. The characteristics and level of noise also can be strongly dependent upon recording location and time. By correcting the detected call counts for these environmental effects, along with assigning uncertainty to the resulting environmentally-calibrated call density estimates, scientifically meaningful conclusions about the calling characteristics of the whales themselves can be obtained.

The specific approach being followed to accomplish objectives 1-4 above is listed below.

1) Detailed numerical modeling of humpback whale call propagation (as in Helble et al., 2013a) is being conducted at a number of "High-frequency Acoustic Recording Package" (HARP) monitoring sites off the California coast. The low-frequency content of these animals' calls makes it imperative to account for the frequency-dependent, complex waveguide effects in call propagation. The best available water column and ocean bottom archival information presently is being assembled to support this modeling effort. The C version of the Range-dependent Acoustic Model ("CRAM"), a parabolic equation-based numerical model developed by Richard Campbell and Kevin Heaney of OASIS for optimal numerical efficiency, continues to be the basis of the numerical modeling. One goal of the modeling is to determine the appropriate frequency spacing required for synthesizing the humpback calls in the time domain. (In previous work, the frequency spacing of 0.2 Hz was much smaller than that required to accurately synthesize the humpback call waveforms). Another goal has been to extend the modeling to source-receiver ranges greater than 20 km for lower-frequency baleen whale calls and in certain situations where efficient long range propagation can occur (e.g., at Hoke Seamount). Humpback calls are detected in the HARP data collected at these sites using the Generalized Power Law (GPL) detector (Helble et al., 2012) and the resulting call counts are being calibrated for environmental effects using the estimated probability of detection (re Helble et al., 2013a,b). The corresponding statistical uncertainties of the calibrated call densities also will be calculated (as presented in Helble et al., 2013c). These calibrated call density estimates then can be converted into animal density estimates, through normalization by an estimate of the average call (cue) rate (Marques et al., 2009). This work will be coordinated with Tyler Helble's 322-MMB project "Obtaining Cue Rate Estimates for Some Mysticete Species using Existing Data" in order to use the best available humpback call rate estimates.

2) A main component of incorporating detection theory formalism into the acoustic density estimation procedure was completed earlier this year, before the funds for this project were received. The results have been included in Helble et al., 2013c.

3) Detailed numerical modeling will be conducted of the propagation of humpback whale vocalizations originating in the shallow water reef areas just west of Kauai, Hawaii to the Pacific Missile Range Facility (PMRF) hydrophones in deeper water offshore (re Fig. 1). The approach will follow that in 1) above. The goal will be to understand the distortions caused by propagation to determine whether or not they can be used to help localize the calling animals. Application of waveguide invariant methods will be investigated as part of this effort. Propagation distortions will be particularly strong over the shallow portion of the path, the biogenic reef off fringing

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Kauai. The sediments in this region are a composite of coarse-grained carbonate and fine-grained volcanic sediments (Fig. 1b) that are poorly sorted compared to the well sorted, fine-grained quartz sediments of terrigenous origin often found in other shallow water environments.
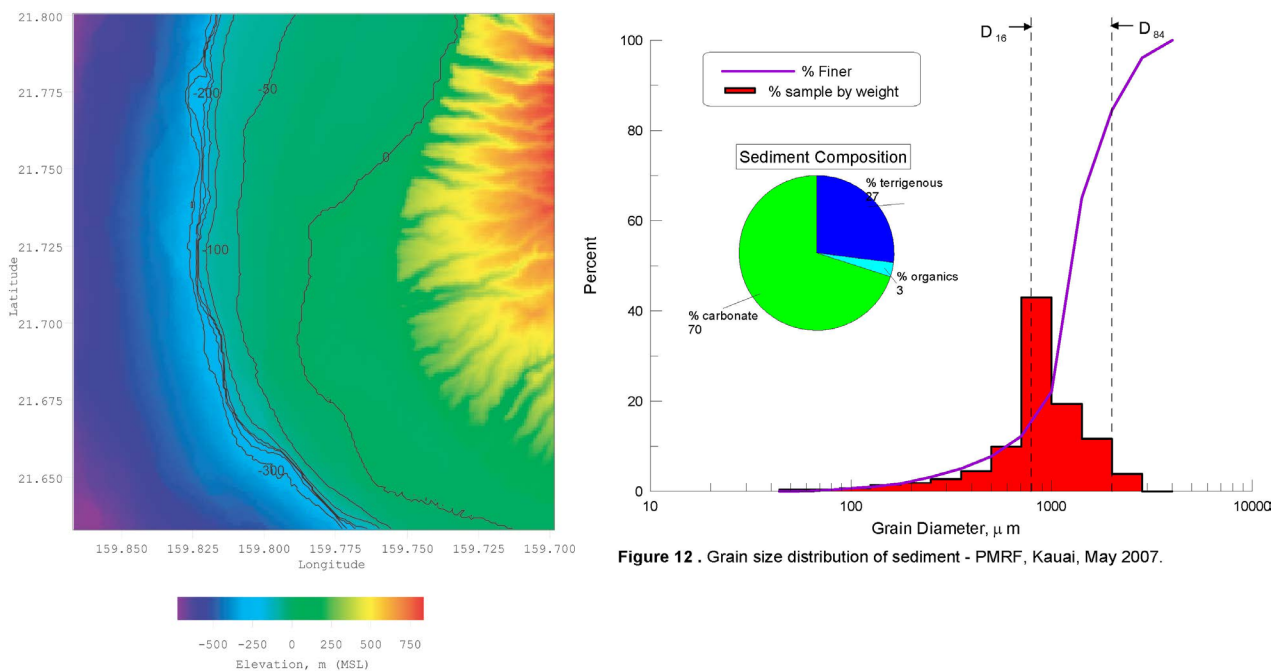

Figure 12. Grain size distribution of sediment - PMRF, Kauai, May 2007.

Figure 1. (Left) The bathymetry west of Kauai derived from the National Ocean Survey (NOS) digital database (depth contours in meters MSL), and (Right) the sediment grain size distribution at PMRF.

4) New methods of spatial and spatiotemporal statistical analyses and spatial correlation analyses will be applied to marine mammal and other bioacoustic sounds in the Southern California Bight. These statistical procedures hold significant promise for identifying patterns they may have biological significance and for providing new information on marine mammal behavior. Spatial correlations with man-made underwater sounds, with physical properties of the environment, and with fields relevant to the biological productivity of the water column also will be conducted. Since much of the software to perform these analyses already exists, the approach to achieve this objective involves mostly the collection of the relevant data bases. This effort also likely will involve acoustic localization of marine mammal calls using a data set collected off the southern California coast in 1999.

The graduate student who was working in this project her first year in the Applied Ocean Sciences curricular group decided to move onto another research project after successfully passing her Departmental exam at the end of spring quarter, 2014. Fortunately, as the recipient of a Regents Fellowship, she came at no cost to the program that first year. To find a suitable replacement, we have been in contact with prospective graduate students interested in the field of bioacoustics. One very promising candidate is finishing her joint degree in marine biology and physics, with minors in math and ocean sciences. In addition, two senior undergraduate students from the UCSD departments of electrical and mechanical engineering, respectively, have recently joined our research group. Their

initial research focus is on learning about the GPL detector and using it on our passive acoustic marine mammal monitoring data sets. Ultimately, we want to compare the GPL performance to matched-spectrogram-based detectors for detecting and classifying transient sounds of biological origin. The GPL detector is based on a power-law processor, which is the optimal detector for transient signals when no *a prioi* knowledge of the arriving signal exists. The family of power-law processors includes the energy detector. However, for stereotyped calls where propagation effects are not too strong, a matched-spectrogram-based detector may have better performance.

The work in this project was leveraged with other ongoing programs, listed in Related Projects below.

WORK COMPLETED

Soon after the initial funding for this project arrived in house at the end of August, 2013, a modern workstation was acquired to perform the computationally intensive acoustic propagation modeling and data analysis. All necessary software to perform the research in this program was installed on this computer. It now is being used not only in this program, but also in our Living Marine Resources program.

Numerical modeling out to 100 km range in 1-deg azimuthal steps and 10-m steps in depth is being conducted for 6 HARP sites in the Southern California Bight. Modeling at additional sites also may be conducted now that the processing chain has been set up on numerous computers.

To support the numerical modeling, data bases of environmental properties and publications on previous research on ocean acoustic propagation offshore southern California were consulted for the relevant information. Of particular interest was information necessary to create geoacoustic models of the ocean bottom/sub-bottom using Hamilton's empirical equations (Hamilton, 1980). Although a few areas in the Southern California Bight have been well studied, and useful information on various properties of the ocean bottom is readily available, the uncertainty in the geoacoustic properties is the largest contributor to the error bounds on the estimates of environmentally calibrated call counts over the frequency band of baleen whale calls.

Note that the computer code for performing all steps required to environmentally calibrate raw detected call counts for baleen whales has been rewritten, enhanced, and documented as part of our LMR project. This code presently is being used to environmentally calibrate the detected call counts in this project.

Passive acoustic recordings at HARP sites M, N, and H covering all seasons were acquired from John Hildebrand's Whale Acoustic Group. These data have been combined with those from HARP sites in the Santa Barbara Channel and at Hoke Seamount (discussed in Helble et al., 2013a). In addition, 3 disks containing 2 to 3 days of data recording from the bottom-mounted hydrophones at the Navy SCORE Range have been acquired. A program to transcribe these data from their recorded binary format into one useable with Matlab and in-house processing software has been written, and all SCORE data have been converted.

As mentioned under Approach above, a major part of the effort at incorporating statistical detection theory into animal density estimation from passive acoustic recordings was completed. In addition, a formal statistical framework for determining the uncertainty in the estimates of environmentally

calibrated call counts in the baleen whale frequency band has been derived and incorporated into Helble et al., 2104a.

An effort has been started on examining the statistics of animal call distributions in space and time. A few initial results are presented in the next section.

Effort was spent on the theoretical development and geophysical inverse theory methods behind optimal localization with hydrophones having overlapping coverage. This effort supported the writing of a paper on localizing calling humpback whales on the Pacific Missile Range Facility, which has been accepted for publication in the Journal of the Acoustical Society of America (Helble et al., 2014b). Finally, a paper to Endangered Species Research is nearly ready for submission (Helble et al., 2014a). In addition, two presentations were given at the June, 2013 "Detection, Classification, Localization, and Density Estimation" workshop in St. Andrews, Scotland (D'Spain et al., 2013; Helble et al., 2013c).

RESULTS

The efforts in this program are a continuation and extension of the work performed in previous projects. Most of the results from those efforts appear in Helble et al., 2012; 2013a; 2013b. A few results in this project are:

- To achieve optimal performance in those cases where results are not required in real time, the detector threshold should be set so that all humanly detectable calls are detected by the autonomous processor. Trained analysts then can examine the resulting detections to eliminate any false detections, reducing the probability of false alarm to effectively zero. This approach provides human-level detection and classification performance while reducing the human work load by a significant amount (an amount that depends upon the percentage of uninteresting data that the autonomous detector is able to winnow out from consideration).

- Setting the detector threshold to a higher level in order to reduce the uncertainty in the estimated probability of detection (by reducing the areal coverage and therefore the impact of the uncertainty in ocean bottom properties) does not help reduce the overall uncertainty in the environmentally-calibrated call detection estimates. Rather, it only introduces a non-zero probability of false alarm (which equals zero when the areal coverage includes all detectable calls), and the associated uncertainty in the estimate of this probability.

- The statistical framework for calculating the bias and variance in the estimates of environmentally calibrated baleen whale call counts (now incorporated into Helble et al., 2014a) shows that the estimate variance at baleen whale frequencies is dominated by a) the variance in noise level, and b) the variance due to uncertainty in calling animal location. In contrast, the geoacoustic properties of the ocean bottom can be modeled as deterministic rather than stochastic, but the uncertainty in these properties results in a significant bias in the estimates in most cases. Whereas nothing can be done to reduce the noise variance (except possibly to choose alternative sensor deployment sites), sensors with directional capability (e.g., acoustic vector sensors) and/or overlapping coverage reduce, or eliminate, the variance due to calling animal location, and results from in situ acoustic calibration runs can reduce the bias.

- Whereas the ocean bottom geoacoustic property of greatest influence at humpback whale frequencies (150-1800 Hz) is the type of sediment (quantified by the sediment grain size), it is the overall sediment thickness for the lower-frequency (10-200 Hz band) baleen whale calls.

- The GPL detector performance is significantly improved at HARP sites M, N, and H compared to the Santa Barbara Channel site. In particular, the false alarm rate is much lower since transient shipping noise, which can trigger the detector, is not prevalent in the recordings at the former sites. Because of ship noise and other sources of low-frequency ocean sound, the GPL detector false alarm rates are significantly higher for fin whale and Type D blue whale calls, as discovered in our LMR project.

- The spatial distribution of locations of calling animals during one experiment display statistically significant clustering for all call types using the nearest neighbor test. One call type shows significantly greater clustering than other call types. These results may reflect a behavioral context for this call type (e.g., call/counter-calling between a mother/calf pair).

- Localizing calling marine mammals using hydrophones with overlapping coverage (e.g., the Navy range hydrophones at baleen whale frequencies) eliminates the need to environmentally calibrate the call counts and thereby reduces significantly the uncertainties in the estimated animal densities obtained from passive acoustic recordings.

IMPACT/APPLICATIONS

Passive underwater acoustic monitoring of marine mammal sounds is the Navy's primary method for characterizing the presence, distribution, and number of marine mammal species in a wide variety of environments, particularly those associated with Navy training ranges. Marine mammal population density estimates are particularly important in regions of Navy activities, or potential activities, in order to properly evaluate their potential impact under federal environmental legislation. Understanding, and improving, this passive acoustic monitoring capability will decrease the environmental risk of Navy training exercises and other activities. Both the southern California Bight region and the area west of Kauai are areas of operational/training interest to the Navy. In addition, since these research efforts involve students in the field of marine bioacoustics at the Scripps Institution of Oceanography, as part of the thesis research, this project will help provide the Navy with the future generation of highly trained ocean bioacousticians aware of both Navy needs and environmental issues.

RELATED PROJECTS

The efforts in this project will be heavily leveraged with other programs. First, efforts in our Living Marine Resources project titled "Improving the Navy's Automated Methods for Passive Underwater Acoustic Monitoring of Marine Mammals" are focused on modifying the GPL processor for detecting a wide variety of marine mammal calls recorded by Navy range monitoring systems (the range hydrophones at the SCORE and PMRF ranges, and John Hildbrand's HARP packages in southern California), and environmentally calibrating the resulting detected call counts in the HARP data. Call rate estimates from Tyler Helble's ONR Code 322-MMB project "Obtaining Cue Rate Estimates for Some Mysticete Species using Existing Data" will be used to derive animal density estimates from the calibrated call densities. Participation by senior-class undergraduate students from the UCSD Electrical and Mechanical Engineering departments was arranged by the UCSD Vice Chancellor of Academic Research. Algorithms from our "Glider-Based Passive Acoustic Monitoring Techniques in

the Southern California Region", Code 322-MMB, are used to automatically scan the data for marine mammal calls and other biological sounds.

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